DALITZ ANALYSIS OF $B^+ \to K^+\pi^+\pi^-$ AND $B^+ \to K^+K^+K^-$

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We report results of the Dalitz analysis of the three-body charmless $B^+ \to K^+\pi^+\pi^-$ and $B^+ \to K^+K^+K^-$ decays based on a 140 fb^{-1} data sample collected with the Belle detector. Measurements of branching fractions for quasi-two-body decays to scalar-pseudoscalar states: $B^+ \to f_0(980)K^+$, $B^+ \to K_0^*(1430)^0\pi^+$, and to vector-pseudoscalar states: $B^+ \to K^*(892)^0\pi^+$, $B^+ \to \rho^0 K^+$, $B^+ \to \phi K^+$ are presented. Upper limits on decays to some pseudoscalar-tensor final states are reported. We also report the new measurement of the $B^+ \to \chi_{c0}K^+$ branching fraction in two χ_{c0} decay channels: $\chi_{c0} \to \pi^+\pi^-$ and $\chi_{c0} \to K^+K^-$.

1 Introduction

Studies of B meson decays to three-body charmless hadronic final states are a natural extension of studies of decays to two-body charmless final states. Some of the final states considered so far as two-body (for example, $\rho\pi$, $K^*\pi$, etc.) proceed via quasi-two-body processes involving a wide resonance state that immediately decays in the simplest case to two particles, thereby producing a three-body final state. B meson decays to three-body charmless hadronic final states may provide new possibilities for CP violation searches.

Observation of B meson decays to various three-body charmless hadronic final states has already been reported by the Belle [1,2,3], CLEO [4] and BaBar [5] Collaborations. First results on the distribution of signal events over the Dalitz plot in the three-body $B^+ \to K^+\pi^+\pi^-$ and $B^+ \to K^+K^+K^-$ decays are described in Ref. [1]. With a data sample of 29.1 fb^{-1} a simplified analysis technique was used because of lack of statistics. Using a similar technique, the BaBar collaboration has reported results of their analysis of the Dalitz plot for the decay $B^+ \to K^+\pi^+\pi^-$ with a 56.4 fb^{-1} data sample [6]. With the large data sample that is now available, we can perform a full amplitude analysis. The analysis described in this paper is based on a 140 fb^{-1} data sample containing 152 million $B\bar{B}$ pairs, collected with the Belle detector operating at the KEKB asymmetric-energy e^+e^- collider.

2 Amplitude Analysis

Analysis of two-body mass spectra shows that a significant fraction of the signals observed in $B^+ \to K^+\pi^+\pi^-$ and $B^+ \to K^+K^+K^-$ decays can be assigned to quasi-two-body intermediate states. These resonances will cause a non-uniform distribution of events in phase space that can be analyzed using the technique pioneered by Dalitz. Multiple resonances that occur nearby in phase space will interfere and provide an opportunity to measure both the amplitudes and relative phases of the intermediate states. This in turn allows us to deduce their relative branching fractions. Details of the event selection and amplitude analysis could be found in the Belle contributed paper [7]. Here we can present the main results only. The examples of the two-body invariant mass distributions and their description by a fit of $B^+ \to K^+\pi^+\pi^-$ and $B^+ \to K^+K^+K^-$ decays are presented in Fig. 1. Results on the branching fractions for quasi-two-body decays are summarized in Table 1.
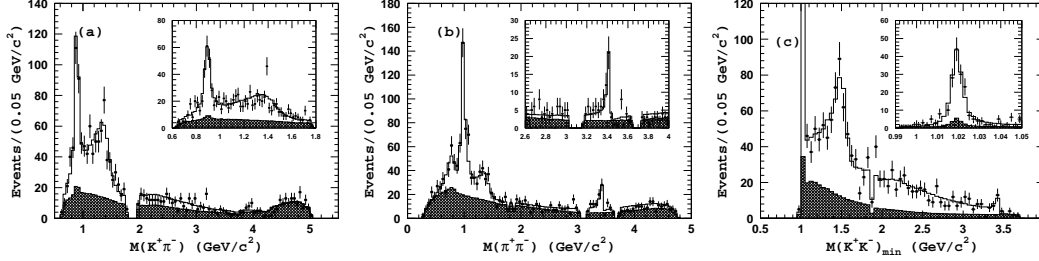
Figure 1. Results of the fit to $K^+\pi^+\pi^-$ and $K^+K^+K^-$ events. Points with error bars are data, the open histograms are the fit result and hatched histograms are the background components. Insets show: (a) the $K^*(892) - K_0^*(1430)$ mass region in 20 MeV/c^2 bins; (b) the χ_{c0} mass region in 25 MeV/c^2 bins; (d) the $\phi(1020)$ mass region in 2 MeV/c^2 bins.

Table 1. Summary of branching fraction results. The first quoted error is statistical, the second is systematic and the third is the model error. The charmless total fractions in this table exclude the χ_{c0} contribution. The value given in brackets for the $K_0^*(1430)\pi^+$ and $\chi_{c0}K^+$ channels corresponds to the second solution (see [7] for details).

Mode	$\mathcal{B}(B^+ \to Rh^+)$ $\times \mathcal{B}(R \to h^+h^-) \times 10^6$	$\mathcal{B}(B^+ \to Rh^+) \times 10^6$
$K^+\pi^+\pi^-$ charmless total	–	$46.6 \pm 2.1 \pm 4.3$
$K^*(892)^0\pi^+$, $K^*(892)^0 \to K^+\pi^-$	$6.55 \pm 0.60 \pm 0.60^{+0.38}_{-0.57}$	$9.83 \pm 0.90 \pm 0.90^{+0.57}_{-0.86}$
$K_0^*(1430)\pi^+$, $K_0^*(1430) \to K^+\pi^-$	$27.9 \pm 1.8 \pm 2.6^{+8.5}_{-5.4}$	$45.0 \pm 2.9 \pm 6.2^{+13.7}_{-8.7}$
	$(5.12 \pm 1.36 \pm 0.49^{+1.91}_{-0.51})$	$(8.26 \pm 2.20 \pm 1.19^{+3.08}_{-0.82})$
$K^*(1410)\pi^+$, $K^*(1410) \to K^+\pi^-$	< 2.0	–
$K^*(1680)\pi^+$, $K^*(1680) \to K^+\pi^-$	< 3.1	–
$K_2^*(1430)\pi^+$, $K_2^*(1430) \to K^+\pi^-$	< 2.3	–
$\rho^0(770)K^+$, $\rho^0(770) \to \pi^+\pi^-$	$4.78 \pm 0.75 \pm 0.44^{+0.91}_{-0.87}$	$4.78 \pm 0.75 \pm 0.44^{+0.91}_{-0.87}$
$f_0(980)K^+$, $f_0(980) \to \pi^+\pi^-$	$7.55 \pm 1.24 \pm 0.69^{+1.48}_{-0.96}$	–
$f_2(1270)K^+$, $f_2(1270) \to \pi^+\pi^-$	< 1.3	–
Non-resonant	–	$17.3 \pm 1.7 \pm 1.6^{+17.1}_{-7.8}$
$K^+K^+K^-$ charmless total	–	$30.6 \pm 1.2 \pm 2.3$
ϕK^+, $\phi \to K^+K^-$	$4.72 \pm 0.45 \pm 0.35^{+0.39}_{-0.22}$	$9.60 \pm 0.92 \pm 0.71^{+0.78}_{-0.46}$
$\phi(1680)K^+$, $\phi(1680) \to K^+K^-$	< 0.8	
$f_0(980)K^+$, $f_0(980) \to K^+K^-$	< 2.9	
$f_2'(1525)K^+$, $f_2'(1525) \to K^+K^-$	< 2.1	
$a_2(1320)K^+$, $a_2(1320) \to K^+K^-$	< 1.1	
Non-resonant	–	$24.0 \pm 1.5 \pm 1.8^{+1.9}_{-5.7}$
$\chi_{c0}K^+$, $\chi_{c0} \to \pi^+\pi^-$	$1.37 \pm 0.28 \pm 0.12^{+0.34}_{-0.35}$	–
$\chi_{c0}K^+$, $\chi_{c0} \to K^+K^-$	$0.86 \pm 0.26 \pm 0.06^{+0.20}_{-0.05}$	–
	$(2.58 \pm 0.43 \pm 0.19^{+0.20}_{-0.05})$	–
$\chi_{c0}K^+$ combined	–	$196 \pm 35 \pm 33^{+197}_{-26}$

3 Discussion

With a 140 fb^{-1} data sample collected with the Belle detector, we have performed the

first amplitude analysis [a] of B meson decays to the three-body charmless $K^+\pi^+\pi^-$ and $K^+K^+K^-$ final states. Such analysis often suffers from uncertainties related to the non-unique description of the decay amplitude. In our case the uncertainty comes mainly from the parametrization of the non-resonant amplitude. It is worth noting that fractions of the non-resonant decay in both $B^+ \to K^+\pi^+\pi^-$ and $B^+ \to K^+K^+K^-$ decays are comparable in size and comprise a significant fraction of the total three-body signal, which may indicate the common nature of the amplitudes.

Despite the large model uncertainty discussed above, there is a set of quasi-two-body signals whose branching fractions can be measured with a relatively small model error. In particular, clear signals are observed in the $B^+ \to K^*(892)^0\pi^+$, $B^+ \to \rho^0(770)K^+$, $B^+ \to f_0(980)K^+$ and $B^+ \to \phi K^+$ decay channels. The model uncertainty for these channels is small due to the narrow width of the resonances and in vector-pseudoscalar decays due to the clear signature of the vector meson polarization.

The branching fraction value measured for the decay $B^+ \to K^*(892)^0\pi^+$ is significantly lower than that reported earlier [1,6]. The simplified technique used for Dalitz analysis of the $B^+ \to K^+\pi^+\pi^-$ decay described in [1,6] has no sensitivity to the relative phases between different resonances, resulting in a large model error. The full amplitude analysis presented in this paper consistently treats effects of interference between different quasi-two-body amplitudes thus reducing the model error. The analysis suggests the presence of a large non-$K^*(892)^0\pi^+$ (presumably non-resonant) amplitude in the mass region of the $K^*(892)^0$ that absorbs a significant fraction of the B signal. The $B^+ \to K^*(892)^0\pi^+$ branching fraction measured in our analysis is in better agreement with theo-

retical predictions based on the QCD factorization approach.

The decay mode $B^+ \to f_0(980)K^+$ is the first observed example of a B decay to a charmless scalar-pseudoscalar final state. The mass $M(f_0(980)) = 976 \pm 4^{+2}_{-3}$ MeV/c^2 and width $\Gamma(f_0(980)) = 61 \pm 9^{+14}_{-8}$ MeV/c^2 obtained from the fit are in agreement with previous measurements. The sensitivity to the $B^+ \to f_0(980)K^+$ decay in the $K^+K^+K^-$ final state is greatly reduced by the large $B^+ \to \phi K^+$ signal and by the scalar non-resonant amplitude. No statistically significant contribution from this channel to the $K^+K^+K^-$ three-body final state is observed, thus only a 90% confidence level upper limit for the product of the corresponding branching fractions is reported.

We report the first observation of the decay $B^+ \to \rho^0(770)K^+$. This is one of the channels where large direct CP violation is expected.

Due to the very narrow width of the ϕ meson, the branching fraction for the decay $B^+ \to \phi K^+$ is determined with a small model uncertainty.

A clear signal is also observed for the decay $B^+ \to \chi_{c0}K^+$ in both $\chi_{c0} \to \pi^+\pi^-$ and $\chi_{c0} \to K^+K^-$ channels. Although quite significant statistically, the $B^+ \to \chi_{c0}K^+$ signal constitutes only a small fraction of the total three-body signal and thus suffers from a large model error, especially in the $K^+K^+K^-$ final state. For this decay mode, the charmless non-resonant amplitude in the χ_{c0} mass region is enhanced compared to the $K^+\pi^+\pi^-$ final state due to the interference caused by the presence of the two identical kaons.

For other quasi-two-body channels the interpretation of fit results is less certain. Although the $B^+ \to K_0^*(1430)\pi^+$ signal is observed with a high statistical significance, its branching fraction is determined with a large model error. Two solutions with significantly different fractions of the $B^+ \to K_0^*(1430)\pi^+$

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[a] At this Conference Babar presented the Dalits plot analysis for $K^+\pi^+\pi^-$ [8].

signal but similar likelihood values are obtained from the fit to $K^+\pi^+\pi^-$ events. A study with MC simulation confirms the presence of the second solution. This may indicate that in order to choose a unique solution additional external information is required. In this sense, the most useful piece of information seems to be the phenomenological estimation of the $B^+ \to K_0^*(1430)\pi^+$ branching fraction. The analysis of B meson decays to scalar-pseudoscalar final states described in Ref. [9] suggests that the branching fraction for the $B^+ \to K_0^*(1430)\pi^+$ decay can be as large as 40×10^{-6}. Unfortunately, the predicted value suffers from a large systematic error that is mainly due to uncertainty in the $K_0^*(1430)$ decay constant $f_{K_0^*(1430)}$. Different techniques used to estimate $f_{K_0^*(1430)}$ [9,10] give significantly different results. Further improvement in this field would be useful.

We also check possible contributions from B decays to various pseudoscalar-tensor (PT) states. In the factorization approximation, charmless B decays to PT final states are expected to occur at the level of 10^{-7} or less. We find no statistically significant signal in any of these channels. As a result, we set 90% confidence level upper limits for their branching fractions.

We cannot identify unambiguously the broad structures observed in the $M(\pi^+\pi^-) \simeq$ 1.3 GeV/c^2 mass region in the $K^+\pi^+\pi^-$ final state denoted as $f_X(1300)$ in our analysis and at $M(K^+K^-) \simeq 1.5$ GeV/c^2 in the $K^+K^+K^-$ final state denoted as $f_X(1500)$. If approximated by a single resonant state, $f_X(1300)$ is equally well described by a scalar or vector amplitude. Analysis with higher statistics might allow a more definite conclusion. The best description of the $f_X(1500)$ is achieved with a scalar amplitude with mass and width from the fit consistent with $f_0(1500)$ states.

Results of the $B^+ \to K^+K^+K^-$ Dalitz analysis can be also useful in connection with the measurement of CP violation in $B^0 \to K_S^0 K^+K^-$ decay reported recently by the Belle [11] and BaBar [12] collaborations. An isospin analysis of B decays to three-kaon final states suggests the dominance of the CP-even component in the $B^0 \to K_S^0 K^+K^-$ decay (after the $B^0 \to \phi K_S^0$ signal is excluded). This conclusion can be checked independently by an amplitude analysis of the $K_S^0 K^+K^-$ final state, where the fraction of CP-odd states can be obtained as a fraction of states with odd orbital momenta. Unfortunately, such an analysis is not feasible with the current experimental data set. Nevertheless, the fact that we do not observe any vector amplitude other than $B^+ \to \phi K^+$ in the decay $B^+ \to K^+K^+K^-$ confirms the conclusion.

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